14.1: Comparison of Blur Edge Time and Gaussian Edge Time as measures of motion blur

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Abstract

Blur Edge Time has been shown to be a reasonable metric for characterisation of motion blur of LCD displays. It can be estimated by taking the 10% to 90% level of the Moving Edge Temporal Profile or by using the standard deviation of a fitted cumulative Gaussian function. In this paper we will compare these two ways of estimating the Blur Edge Time. Ultimately the usefulness of these metrics of motion blur is whether they are good predictors of perceived motion blur.

1. Introduction

Display motion blur is a perceptual phenomenon that is the result of the interaction between the temporal update of a pixel and the visual tracking by the human visual system of a moving object. The visual experience of a moving sharp edge is that it becomes visually broader. It has been shown that this broadening of the edge is linearly dependent on the speed of the edge [1,2]. We refer to the cross-section of a moving edge as the Moving Edge Spatial Profile (MESP). A metric of the width of the edge, called Blur Edge Width (*BEW*), can be defined as the distance between the 10% to 90% level of the profile.

To measure this width directly, a tracking camera that is either moved along the moving edge or utilizing rotating mirrors, or a stationary high speed camera can be used[3-5]. Since it is assumed that *BEW* is linearly dependent on the speed, we generally consider what we call the Moving Edge Temporal Profile (METP) by scaling the MESP with speed. It has been shown [5,6,7] that METP can be derived from the temporal step-response of the display pixels by convolving it with a rectangular pulse of one frame time. This permits to directly use non-imaging device such as photometers to measure the METP.

From this METP an analogous metric to *BEW* can be defined called the Blur Edge Time (*BET*) i.e. by taking the time between the 10% and 90% level of METP. As expected the relationship between *BEW* and *BET* is $BEW = BET \cdot V$. Watson (2009) [8] proposed another metric that consists of fitting a cumulative Gaussian function to the METP. Then the time interval from 10% to 90% of the METP can be estimated from the standard deviation σ of the cumulative Gaussian function. This metric was named Gaussian Edge Time (*GET*).

This paper will compare *BET* and *GET* metrics with each other, on 12 various displays and for 20 different gray-to-gray transitions. For each display and each transition, METP has been measured with a non-imaging device, and only this method has been used here. We will particularly focus on the reproducibility of the estimates and on the correlation between both metrics. Another purpose is to see how well they can predict the results of a user experience evaluation described previously [1].

2. Methodology

2.1 Displays under test

Displays that have been assessed in this work are described in Table 1. All of them are liquid-crystal displays (LCD). They were equipped with various features that are described in Table 1.

2.2 Temporal step response measurements

On each DUT, temporal step-responses of the pixels have been measured for 20 transitions from one gray level (g_{start}) to another (g_{end}) among five. The following gray levels were used: 0, 63, 127, 191, and 255. Each of the 20 gray-to-gray transitions $g_{start} \rightarrow g_{end}$ have been measured 5 times on each DUT, except for DUT3, DUT11 and DUT12 (only twice).

Table 1: Displays under test.

DUTID	Size	Resolution	Type	Note
DUT1	20"	1680x1050	Desktop LCD monitor	
DUT2	24.1"	1920x1200	Desktop LCD monitor	Strong backlight modulations
DUT3	42"	1360x768	LCDTV	LED backlight, local dimming turned off
DUT4	19"	1280x1024	Desktop LCD monitor	
DUT5	15"	1024x768	Desktop LCD monitor	
DUT6	24"	1920x1200	Desktop LCD monitor	Strong backlight modulations
DUT7	26"	1920x1200	Desktop LCD monitor	Scrolling backlight, Overdrive
DUT8	20.1"	1600x1200	Desktop LCD monitor	LED edge backlight
DUT9	40"	1920x1080	LCDTV	LED backlight, local dimming turned off
DUT10	30"	2560x1600	Desktop LCD monitor	Scrolling backlight, Overdrive
DUT11	23"	1920x1200	Desktop LCD monitor	
DUT12	37"	1920x1080	LCDTV	

The light intensity emitted by the display was read by a photodiode positioned in close contact with the screen surface. The photodiode was surrounded by black velvet in order to reduce any scratches to the display surface and to shield any ambient light reaching the photodiode. The photodiode (Burr-Brown OPT101 monolithic photodiode with on chip transimpedance amplifier) has a fast response (28 µs from 10% to 90%, rise or fall time). The signal was read by an USB oscilloscope EasyScope II DS1M12 "Stingray" 2+1 Channel PC Digital Oscilloscope/Logger from USB instruments. The accuracy of the instrument has been tested with an LED light source connected to a function generator.

Each transition has been measured sequentially by displaying each gray level during 20 frames, with a sampling period of 0.1 msec.

2.3 Moving edge temporal Profile

From these temporal step-responses, METP was then computed by convolving the waveform with a rectangular pulse of one frame time, in the same way as described in Tourancheau (2009)[5]. We then trimmed the METP from 15 frames before the transition to 15 frames after. This ensures that this 30-frame long waveform was clean of any residuals from the convolution or from the previous and next transitions.

3. Blur estimates

3.1 BET metric

Blurred Edge Time (BET) is usually measured on the METP as the time interval from 10% to 90% of the METP luminance range. In order to determine 10% and 90% values of the METP, we need to estimate precisely the beginning relative luminance value B and the ending relative luminance value E. This has been done by computing the average luminance value of samples corresponding to the first two frames and to the last two frames (respectively) of the METP.

Since some ripples can remain on METP after the convolution, it could have been necessary to apply some additional processing in order to determine for which samples it crossed the 10% and 90% values. This was done using a filtering with a Gaussian kernel with a standard deviation of 0.15 frames. An example of METP, with smoothed waveform is shown in Figure 1.

3.2 GET metric

The Gaussian Edge Time (*GET*) were measured according to Watson (2010)[8]. The following cumulative Gaussian function was fitted to the METP:

$$G(t) = B + (E - B) \int_{-\infty}^{t} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) dx$$

$$G(t) = E + \frac{B - E}{2} \operatorname{erfc}\left(\frac{t - \mu}{\sigma\sqrt{2}}\right)$$

where E and B are beginning and ending relative luminance values, t is the time in seconds, μ is the mean and σ is the standard deviation of the Gaussian, and erfc is the complementary error function. The parameter σ can be converted to an estimate of *BET* that is referred to as the Gaussian Edge Time (*GET*) by:

$$GET = 2.563\sigma$$

For additional accuracy, the fitting was done twice. First the parameters were estimated from the complete waveform. Then the waveform was trimmed to the mean μ plus and minus a number N_σ of standard deviations σ, and the fitting was repeated. Various values of N_σ have been tested here, and the consistency between *BET* and *GET* has been studied regarding this parameter. An example of METP, with cumulative Gaussian function is shown in Figure 2.

3.3 Overdrive

Overdrive techniques to reduce liquid crystal cells response time can lead to overshoot or undershoot on the temporal step-responses, as well as on the METP. These artifacts are usually taken in account by measuring *BET* from -10% to 110% if these values are reached [9]. Since *GET* metric cannot reflect these particular distortions, we computed *BET* from 10% to 90% even in presence of overdrive, in order to compare both metrics equally.

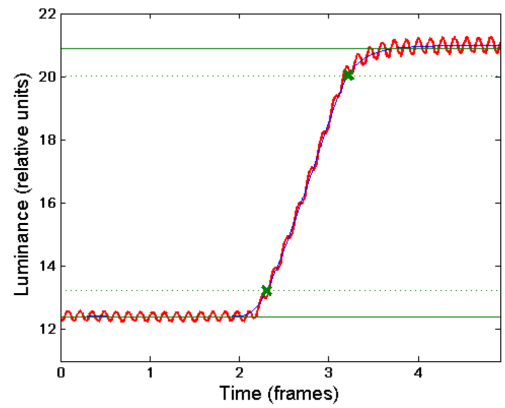

Figure 1: Example of *BET* estimate for DUT10 and transition 191-255. Thick line (red) represents raw METP waveform, thin line (blue) is the smoothed METP waveform. Horizontal lines (green) figure the beginning and ending relative luminance values as well as the 10% and 90% levels. Samples from which *BET* is computed are marked with a cross.

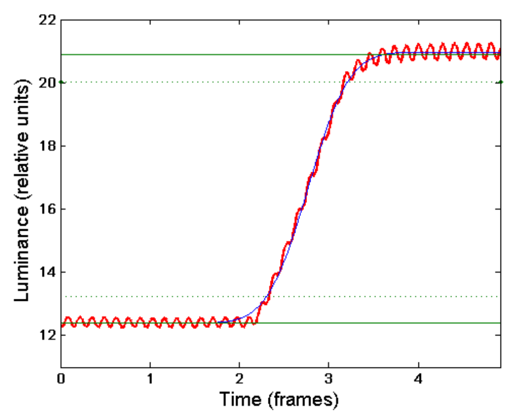

Figure 2: Idem as Figure 1, GET estimate is obtained from the standard deviation of the cumulative Gaussian function obtained from the fitting (thin blue line).

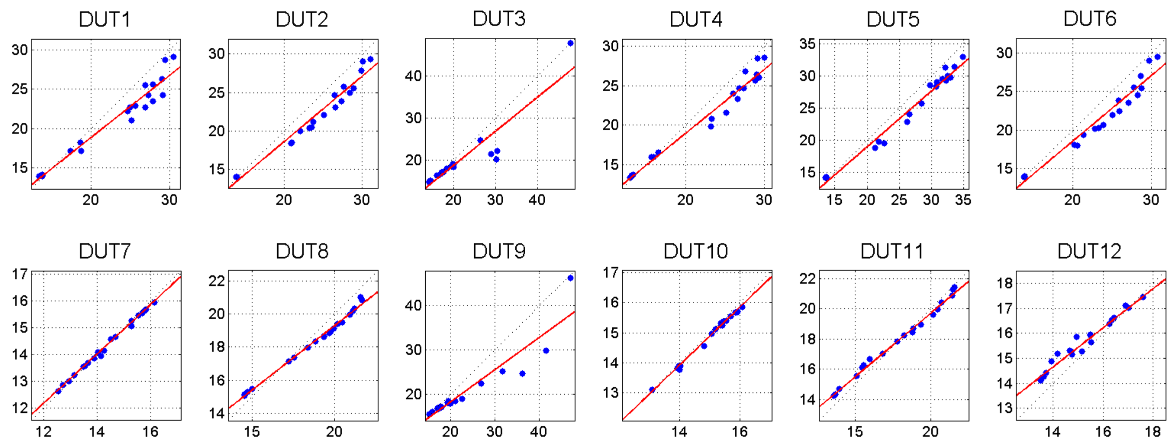

Figure 3: Scatter plot of GET as a function of BET for each DUT.

4. Results

4.1 Correspondence between BET and GET

We compared the correspondence between *BET* and *GET* according to the size of the METP waveform used during the second fitting to determine *GET*. As explained in Section 3.2, a second fitting was performed to increase the accuracy of the parameters. This second fitting was done on a trimmed METP waveform, from $\mu - N_\sigma \cdot \sigma$ to $\mu + N_\sigma \cdot \sigma$, with μ and σ the parameters determined by the first fitting. The size of the METP waveform used for the second fitting was, therefore, $2N_\sigma \cdot \sigma$.

Several values of N_σ were tested: 3, 4, 5, 7, and 10, and the linear correlation coefficient between *BET* and *GET* were computed for each case. Results are presented in Figure 4. It can be observed that the linear correlation coefficient became better as the size of the waveform were increased. Note that when N_σ were higher than 6, all correlation coefficients were higher than 0.96, except for DUT3 and DUT9 which are both LCDTVs with LED backlight.

As a conclusion, if we want *GET* to be a good predictor of *BET*, it is necessary to fit the cumulative Gaussian function on a METP waveform which is large enough. If not, some discrepancies can appear between both metrics due to a bad estimation of beginning and ending relative luminance values in the *GET* computation. In the following, we present a comparison between *BET* and *GET* with a value of N_σ fixed to 10.

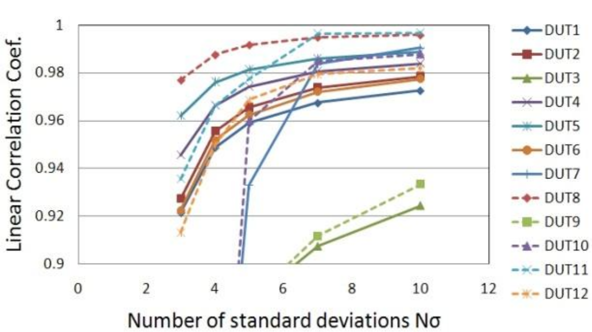

Figure 4: Evolution of the linear correlation coefficient between BET and GET as a function of the size of the METP waveform used to determine GET.

In Figure 5 the correspondence between the two metrics *BET* and *GET* is presented for each display. Table 2 presents the linear correlation coefficient (LCC) and the root-mean-square error (RMSE) between *BET* and *GET* over all measurements and for each display. The linear relation $GET = aBET + b$ is drawn by a red line in Figure 3 and the values of a and b are given in Table 2. On all DUT, the LCC between *GET* and *BET* is 0.969 and the corresponding linear relation is (cf. Figure 5):

$$GET = 0.79 \cdot BET + 3.06$$

Table 2: Linear correlation and root-mean-square error between BET and GET for all DUT.

ID	LCC	a	b	RMSE
DUT1	0.972	0.79	3.05	2.51
DUT2	0.978	0.85	1.61	2.34
DUT3	0.924	0.81	2.53	3.43
DUT4	0.984	0.81	2.73	2.12
DUT5	0.989	0.87	1.54	2.20
DUT6	0.977	0.85	1.53	2.41
DUT7	0.990	0.92	1.14	0.12
DUT8	0.996	0.78	3.68	0.70
DUT9	0.933	0.73	3.60	4.26
DUT10	0.984	0.96	0.48	0.16
DUT11	0.997	0.84	2.88	0.49
DUT12	0.982	0.78	3.73	0.55

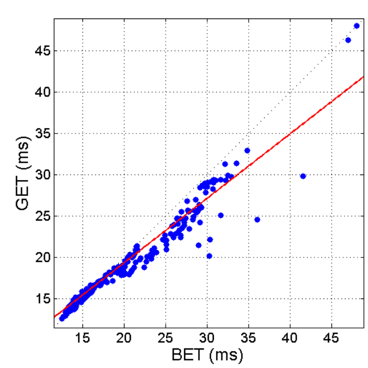

Figure 5: Scatter plot of GET vs BET for all DUT.

4.2 Reproducibility of Measurements

To evaluate the constancy and the reproducibility of measurements, we computed the standard deviation of the set of five measurements for each tested transition. The average of these standard deviation values over the 20 transitions is given for each display in Table 3, except for DUT3, DUT11 and DUT12 which have been measured only twice.

Globally, the average standard deviation between similar measurements is 0.17 for *BET*, and 0.09 for *GET*. We can observe from Table 3 that *GET* gives more stable results than *BET*. On DUT with strong backlight modulations such as DUT2 or DUT10, the METP waveform needs to be filtered to measure *BET*. This leads to high standard deviation values for BET since the position of backlight modulations regarding the frame refresh can be different from one measurement to another. In spite of this, *GET* estimates are particularly stable for these DUT.

Table 3: Average standard deviation of measurements for each DUT and for both metrics

ID	BET	GET
DUT1	0.04	0.05
DUT2	0.47	0.08
DUT4	0.12	0.11
DUT5	0.19	0.14
DUT6	0.14	0.06
DUT7	0.13	0.06
DUT8	0.08	0.06
DUT9	0.16	0.1
DUT10	0.22	0.11

4.3 Comparison with user experience data

In this section we compared the metrics with the results of a user experience described previously [1]. In this subjective experiment users were asked to adjust the blur width of a simulated blurred edge until it matched the motion blur they perceived on a moving edge. From the responses of the observers a Mean Opinion *BET* (*MOBET*) were computed, as a subjective measure of the perceived blur in the used displays. This experiment has been led on 3 DUT: DUT10, DUT11 and DUT12.

If we observe these metrics' correspondence to user experience, the fit is reasonable for such a simple metric with a correlation between *BET* and *MOBET* of 0.785 (RMSE = 2.05) and between *GET* and *MOBET* of 0.780 (RMSE = 2.13). Not surprising considering the close correspondence between the metrics, both *BET* and *GET* have similar fits and it cannot be said that one is better than the other based on this. It is also unclear whether a higher correlation is possible, given the variability among observers.

5. Conclusion

In this paper, we have investigated the relation between the metrics for motion blur *BET* and *GET*. Based on the measurements performed on 12 displays and 20 transitions each, *BET* and *GET* are very similar with a 0.97 correlation. We have shown that if we want *GET* to be a good predictor of *BET* it is necessary to estimate it on a waveform with a large number of samples. However, there is no unique method of estimating BET. For example, result will vary depending on the estimation of beginning and ending luminance values, and on the value of the filter standard deviation when filtering is necessary. From this point of view, GET metric is easier to standardize and permits to obtain similar results from one lab to another since there is no unknown parameters.

Despite the high correlation between *BET* and *GET*, relation between them is not identity. We have observed some discrepancies from one display to another but in a whole we obtained $GET = 0.79 \cdot BET + 3.06$.

Finally, both metrics provide a reasonable prediction of the mean opinion of observers, with a correlation is of 0.79. However, further research is required to build a metric able to predict user experience with accuracy.

6. Acknowledgements

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7. References

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